ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

TECHNICAL REPORT
TR-2229-ENV

OPERATIONAL TEST REPORT (OTR): ON-SITE DEGRADATION OF OILY SLUDGE IN A TEN-THOUSAND GALLON SEQUENCING BATCH REACTOR AT NAVSTA PEARL HARBOR, HI

by

Sonny Maga
Fred Goetz
Edward Durlak

November 2003

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0811

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
November 2003	Final	

4. TITLE AND SUBTITLE	
OPERATIONAL TEST REPORT (OTR): ON-SITE DEGRADATION OF OILY SLUDGE IN A TENTHOUSAND GALLON SEQUENCING BATCH REACTOR AT NAVSTA PEARL HARBOR, HI	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Sonny Maga, Fred Goetz, Edward Durlak	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES Commanding Officer Naval Facilities Engineering Service Center 1100 23rd Avenue Port Hueneme, CA 93043	8. PERFORMING ORGANIZATION REPORT NUMBER TR-2229-ENV
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Commander Naval Facilities Engineering Command Alexandria, VA 22232-2300 Pollution Abatement Ashore Program (Y0817)	10. SPONSOR/MONITORS ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Department of Defense facilities generate thousands of tons of oily sludge annually.

Naval Facilities Engineering Service Center (NFESC) was tasked to conduct bench and pilot-scale testing of oily sludge biodegradation. In collaboration with PWC Pearl Harbor, NFESC designed, installed, and operated a 10,000-gallon sequencing batch reactor (SBR) for the on-site degradation of oily sludge. Research completed by NFESC demonstrated that bacteria already present in and adapted to oily sludge from a variety of sources degrade the hydrocarbons found in oily sludge within two weeks from 20,000 ppm to less than 100 ppm. In addition, the concentrations of heavy metals (primarily zinc and copper) and total suspended solids in treated sludge residuals remain well below discharge limits. Data and results are presented in this report. These results demonstrate that on-site biological treatment is technically and economically feasible and that a sequencing batch reactor is easily assembled on site using off-the-shelf components and surplus tanks. This approach eliminates the sludge at significant cost savings, which for most installations would be recovered in two years, and eliminates the long-term liability associated with landfilling oily sludge.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
U	U	U		18	19b. TELEPHONE NUMBER *(include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

ACKNOWLEDGEMENTS

We wish to thank the Naval Facilities Engineering Command and the Environmental Protection, Safety and Occupational Health Division (N45) of the Chief of Naval Operations for funding and sponsoring this project under the Pollution Abatement Ashore Program.

We are also grateful for the leveraged funds provided by PWC Pearl Harbor, Code 310, which allowed us to procure auxiliary equipment. We greatly appreciate the strong site support from PWC Pearl Harbor personnel during system installation and testing.

The authors would also like to thank the following persons who each provided their own individual talents to the success of the project:

Dr. Fred Goetz, IPA at the University of California Santa Barbara; Mr. Jeff Heath, Branch Head, Pollution Prevention Technology Development Branch, Naval Facilities Engineering Service Center; Mr. Andy Del Collo, NAVFAC Environmental RTD&E Program Manager, Mr. Steve Christiansen, Department Supervisor, Environmental Division, Public Works Center Pearl Harbor; Mr. Allan Esaki, Division Supervisor, Environmental Division, Public Works Center Pearl Harbor; Mr. Dennis Chang, Division Supervisor, Environmental Division, Public Works Center Pearl Harbor; Mr. Andy Yee, BOWTS Supervisor, Environmental Division, Public Works Center Pearl Harbor; Mr. Randal Jones, President, Wastewater Resources Incorporated.

EXECUTIVE SUMMARY

Department of Defense facilities generate thousands of tons of oily sludge annually. Since this waste cannot be recycled or burned, it is drummed and landfilled, and disposal cost to the Navy alone is in excess of $6.5M per year. Due to increasing costs, long-term liability, and restrictions on landfill disposal, cost effective on-site treatment is an attractive option. Naval Facilities Engineering Command under CNO's Pollution Abatement Ashore Program tasked the Engineering Service Center (NFESC) to conduct bench and pilot-scale testing of oily sludge biodegradation. In collaboration with PWC Pearl Harbor, NFESC designed, installed, and operated a 10,000 gallon sequencing batch reactor (SBR) for the on-site degradation of oily sludge. NFESC research concluded that bacteria already present in and adapted to oily sludge from a variety of sources degrade the hydrocarbons found in oily sludge within two weeks from 20,000 ppm to less than 100 ppm. In addition, the concentrations of heavy metals (primarily zinc and copper) and total suspended solids in treated sludge residuals remain well below discharge limits.

The SBR process, system performance, and data results are presented in this report. A summary of significant results are as follows:

- Currently, a degradation cycle requires 5 days. The recirculation pump is turned off and the solids allowed to settle. The ultrafiltration unit requires approximately 16 hours to process the contents of the reactor.

- The concentration of hydrocarbons in the sludge in the reactor after 1.5 years of operation was less than 500 ppm. That was well within the allowable concentration for disposal at the landfarm.

- Copper, nickel, and zinc are the predominant metals that accumulate in the reactor at non-hazardous levels, which is consistent with the origins of the sludge. Lead, chromium, and cadmium were not detected in the liquid phase.

- To minimize (eliminate) the emission of priority pollutants (**B**enzene, **T**oluene, **E**thylbenzene, **X**ylenes (BTEX)), exhaust air from the SBR is passed through compost biofilters (Biocubes). Biofilters routinely remove more than 90% of BTEX from contaminated air. When biodegradation in the SBR (measured >99.5%) is included, total yearly emissions of BTEX are predicted to be less than 16 pounds per year.

- Samples of raw and treated sludge were assayed for toxicity. While raw sludge was toxic in both assays, treated sludge was not toxic in either assay.

These results demonstrate that on-site biological treatment is technically and economically feasible and that a sequencing batch reactor is easily assembled on site using off-the-shelf components and surplus tanks. This approach eliminates the sludge, normally shipped to the mainland, at significant cost savings (disposal costs are reduced from $0.76/lb to $0.08/lb) which for most installations would be recovered in 2 years. The long-term liability associated with landfilling oily sludge is also eliminated.

1.0 INTRODUCTION

Department of Defense (DoD) facilities generate thousands of tons of oily sludge annually at industrial wastewater treatment plants, washracks, fuel depots, industrial operations, and maintenance facilities. Since this waste cannot be recycled or burned, it is drummed and landfilled. The disposal cost to the Navy alone is in excess of $6.5M per year. Due to increasing costs, long-term liability, and restrictions on landfill disposal, cost effective on-site treatment is an attractive option. To address this problem, the Naval Facilities Engineering Command (NAVFAC), under CNO's Pollution Abatement Ashore Program, tasked the Naval Facilities Engineering Service Center (NFESC), Port Hueneme, CA, to conduct bench and pilot-scale testing of oily sludge biodegradation.

NFESC research concluded that bacteria already present in and adapted to oily sludge from a variety of sources degrade the hydrocarbons found in oily sludge within 2 weeks from 20,000 ppm to less than 100 ppm. In addition, the concentrations of heavy metals (primarily zinc and copper) and total suspended solids in treated sludge residuals remain well below discharge limits. These results demonstrated that on-site biological treatment was technically and economically feasible. In collaboration with PWC Pearl Harbor, NFESC designed, installed, and operated a 10,000 gallon sequencing batch reactor (SBR) for the on-site degradation of oily sludge.

2.0 BACKGROUND

Biological treatment is increasingly used to treat a wide variety of organic rich waste streams. The most common application is sewage treatment. Food processors, feed lots, the paper industry, oil refineries, and the automotive industry often use on-site biological treatment for high biological demand waste. In most applications, biological treatment systems are designed to promote the growth of naturally occurring bacteria adapted to grow on and degrade the targeted waste. The basic requirements are that the system be well mixed, maintain a near neutral pH, and for most applications operate aerobically. However, to reduce the amount of residual biomass and to generate methane which is captured and used as fuel, some waste streams are treated anaerobically. To accommodate the longer residence times needed to treat waste anaerobically, the capacity is often much larger than a corresponding aerobic system. When treating industrial waste as opposed to sewage, nitrogen, phosphorus, and low concentrations of vitamins are added to promote bacterial growth. In recent years, technological enhancements, e.g., trickling filters, rotating bio contactors, and activated sludge systems have been developed to maximize bacterial contact with the waste and reduce processing time. However, for most applications a simple stirred tank reactor is sufficient.

Biological treatment will remove more than 90 percent of suspended organic solids and it is the most cost effective treatment available for dissolved organics. Although significant progress has been made in treating compounds once considered recalcitrant, biological treatment of some organic pollutants, such as PCB's is not yet practicable. High concentrations of heavy metals, solvents, salt, and extremes of pH or temperature will

hinder and in some cases poison biological treatment systems. However, these effects are usually transient and systems rapidly recover when normal conditions are restored.

Vigorous aeration of the reactor will produce air emissions and the degradation process itself may produce volatile compounds. However, these compounds are usually biodegradable and one practice is to pass exhaust air through containers filled with compost, a process known as biofiltration. Bacteria in the compost capture and degrade volatile hydrocarbons and some inorganic species, e.g., hydrogen sulfide and ammonia.

Biological treatment produces a residue that is primarily biomass, i.e., bacteria and cell remnants. The volume depends on the capacity of the system and the residence time in the reactor. Since biomass is recycled and broken down during each reactor cycle, the total amount of biomass increases slowly. Most industrial applications will produce 1 to 2% of reactor sludge per gallon of treated oily wastewater. Unless the concentration of metals exceeds allowable limits, the residue is usually non-toxic and non-hazardous and can be captured in a filter press, bag filter, landfarmed, landfilled, or composted. Since biological processes are simple to install and operate and are relatively cheap, they are attractive on-site treatment technologies.

3.0 OBJECTIVES

The objective of the project is to demonstrate and validate an innovative application of a sequencing batch reactor for on-site treatment of oily sludge generated at DoD facilities. Specific objectives of the project were:

- Construct and install a bioreactor using commercially available components.
- Optimize degradation of oily sludge in the reactor.
- Develop protocols for disposing of reactor biomass residuals.
- Develop design, cost, and performance data.

The long-term objective is to promote on-site treatment of oily sludge and similar industrial wastes in sequencing batch reactors at DoD facilities.

4.0 SYSTEM OVERVIEW

4.1 System Description

A schematic diagram of the PWC Pearl Harbor bioreactor installation and associated components is shown in **Figure 1**. The major componets are the reactor, receiving tank, ultrafiltration unit, compost biofilters (Biocubes), and controller. The nature of the waste, and capacity of the tanks dictates that they be installed on a concrete pad with secondary containment. The raw material for the reactor is oily sludge. Sources include but are not limited to fuel tank bottoms, pump stations, wash racks, and oil/water separators. Sludge is delivered via a dedicated pipeline or vacuum trucks to the receiving tank (T1), where it is diluted and run through a trash pump (P1) to produce a homogenous slurry.

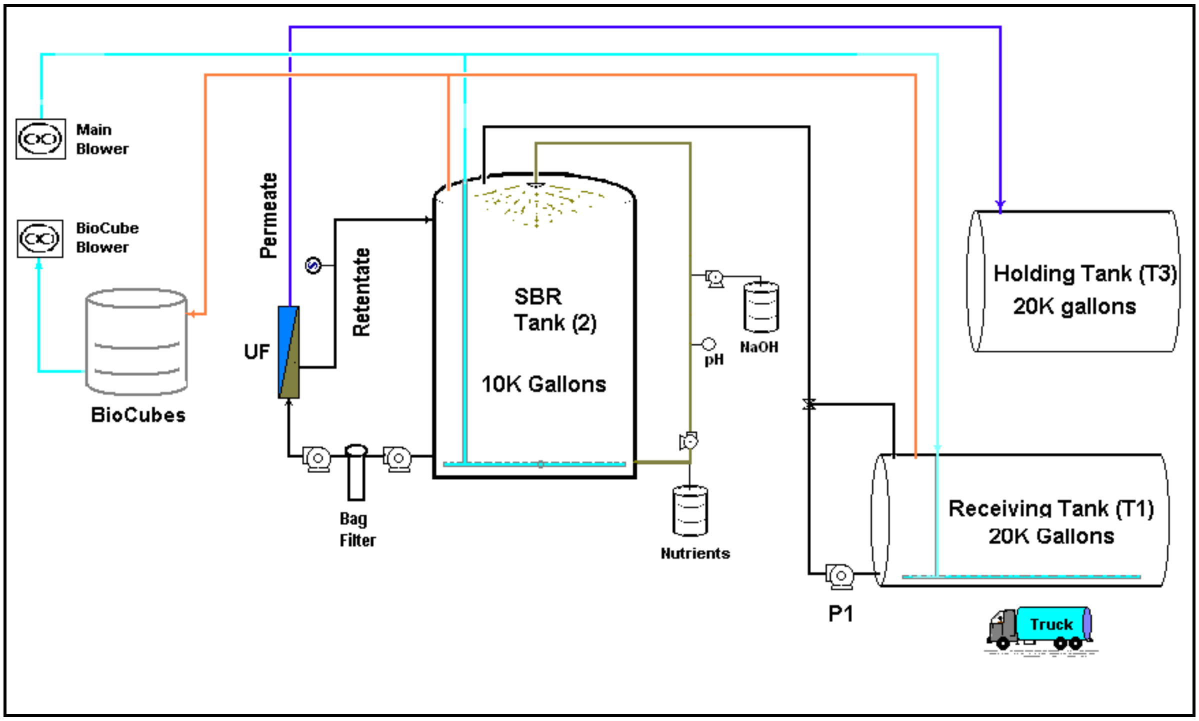

Figure 1. Sequencing Batch Reactor

Schematic of a 10,000 gallon sequencing batch reactor and associated components. BioCubes are used to scrub the exhaust air. The ultrafiltration unit (UF) is used to recycle the biomass. A separate exhaust blower is used to capture air from the receiving tank and reactor. The main blower provides air to the reactor and receiving tank.

The trash pump is also used to transfer sludge to the reactor and to recirculate sludge in the receiving tank. The tank is aerated to reduce the formation of hydrogen sulfide and other noxious reduced sulfur compounds, and to keep the contents of the processing tank from settling. Since the contents of this tank are aerated and recirculated, some degradation will occur.

The reactor tank (T2) has a working capacity of 9,000 gallons and a nominal design capacity of 15,000 to 20,000 gallons per month of diluted sludge, which corresponds to 3,000-4,000 gallons per month of raw sludge. The reactor is equipped with an aeration system, recirculation pump, thermocouple, level sensor and alarm, and sampling ports. Equipping the recirculation inlet with a spray head controls the foaming in the reactor tank. The recirculation pump is plumbed so that a concentrated solution of nutrients (nitrogen, phosphorus, and commercial products that provide amino acids and vitamins) is pumped directly into the recirculation line. To neutralize carboxyclic acids produced during initial degradation of the hydrocarbons and maintain a near neutral pH, a pH controller is used to pump 50% sodium hydroxide into the recirculation line. The production of these intermediates, which are surfactants, is also responsible for the

foaming. As these compounds are degraded, foam formation decreases and the pH stabilizes at about 7.5.

Exhaust air from the reactor and receiving tank are passed through an air filtration system. At PWC Pearl, commercially available compost-filled Biocubes® were used. As air moves through the compost, resident bacteria capture and degrade volatilized hydrocarbons, ammonia, and hydrogen sulfide. This technology was evaluated using the 75-liter reactor in preliminary studies conducted by NFESC. Compost biofilters are a rapidly maturing technology that are used to control odors at sewage treatment plants and industries that emit biodegradable volatile organic compounds, e.g., paint spray booths.

At the end of a reaction cycle (original target 10 days, currently 5 days), the aeration system and recirculation pump are turned off and solids settle to the bottom of the reactor. After settling, the supernatant is passed through a bag filter and ultrafilter. Suspended solids (primarily biomass) are recycled to the receiving tank. The bag filter installed upstream of the ultrafiltration module removes larger particles which reduces fouling of the ultrafiltration membranes. Clean effluent from the ultrafiltration unit is sent to a 20,000 gallon holding tank (T3) and either discharged to the sewer or used as make-up water for incoming sludge. Comprehensive analyses, **Table 1**, were conducted during SBR operation and prior to the release of solids and permeate.

Table 1. Sampling, Analyses, and Monitoring of the SBR

Parameter	Bioreactor			Method
	Oily Sludge	Ultrafiltrate Permeate	Ultrafiltrate Retentate	
Hydrocarbons	Weekly Samples			8015M and 4030
Total Suspended Solids (TSS)	Weekly Samples			Standard Method 2540 D
pH	pH electrode for continuous monitoring			Calibrated pH Electrode
Phosphate Nitrate and ammonia	Weekly Samples			Ion Chromatography Standard Method 4110 B
Metals	Beginning and End			Standard Method 3120 B ICP
Temperature	Thermocouple for continuous monitoring			Calibrated Thermocouple

Once the reactor was assembled and tested hydraulically tested, it was used to determine the maximum hydrocarbon loading that could be degraded within the designed retention time of 5 to 10 days. This phase required nine months during which time hydrocarbon loading, concentration of nutrients, and biomass recycle were systematically varied and

optimized. This phase was guided by data generated during the bench-scale studies that closely approximated the behavior of the 10,000-gallon reactor. Data collected from ongoing operation of the reactor at PWC Pearl Harbor will be used to guide the design, purchase of components, installation, and operation of reactors at other activities.

Originally, biomass that accumulates in the reactor was going to be disposed by adding it to compost piles at the Navy operated composting facility at the former NAS Barbers Point. However, segregation and testing of the compost was prohibitive and a permit was obtained that allows accumulated biomass to be disposed at the Navy operated and permitted landfarm.

When composting is an option, the impact of residual biosolids on composting will be evaluated by the ability of the compost piles to maintain composting temperature and decreases in fecal bacteria (if biosolids from sewage treatment plants are part of the compost recipe). If the performance and analyses of reactor biomass amended compost piles is comparable to regular compost piles, then the piles will be allowed to mature. If reactor biomass amended compost piles do not meet permit requirements, composting will either continue or the piles will be landfilled. However, residual biomass in the SBR is not expected to impact composting or compost quality. When composting is not an option, biosolids will be captured in a bag filter or filter press, analyzed, and disposed of in a conventional landfill.

4.2 System Performance

In collaboration with Public Works Center (PWC) Pearl Harbor, NFESC designed, installed, and is operating a sequencing batch reactor capable of treating 3,000 to 4,000 gallons of oily sludge per month, **Figure 2**. To achieve the high bacterial densities that promote rapid biodegradation and eliminate the need for a clarifier, the system uses an ultrafiltration module to concentrate and recycle sludge degrading bacteria. This innovative use of an ultrafilter allows a 3 to 4 fold reduction in the size of the SBR. The liquid stream (permeate) that passes through the ultrafilter is a dilute solution of salts and nutrients that is either discharged to the sewer or used to dilute incoming oily sludge prior to charging the reactor.

This unique approach eliminates the need for landfilling and results in complete degradation of hydrocarbons and other organic components in the sludge, leaving only process water and biomass as non-toxic byproducts. During FY03, the SBR successfully treated more than 50,000 gallons of oily sludge from the bilge oily wastewater treatment system (BOWTS) unit and shipyard oily waste holding tanks.

The actual cost of biological treatment is \$0.08/lb, which includes operation and maintenance (O&M), and equipment depreciation. In contrast, shipping oily sludge from Hawaii to the mainland costs an average of \$0.76/lb and the Navy remains liable for landfilled sludge. Thus, biological treatment results in a cost savings of 90 % and eliminates liability. This project demonstrated that a complete reactor could be assembled using off-the-shelf components and surplus tanks.

Figure 2. Completed Installation at NAVSTA Pearl Harbor, HI.
From left-to-right are the control room and blower facilities, biocubes, ultrafiltration module, reactor, and tanks for receiving sludge and storing ultrafiltrate permeate.

4.3.3 Process Description. Oily sludge is delivered to the receiving tank where it is diluted with permeate from the ultrafiltration unit, city water or a combination of the two. In addition, ultrafiltrate reject, which is mostly biomass, is discharged to this tank. During operation of the ultrafiltration unit, discharging to this tank rather than the reactor minimizes resuspension of settled solids in the reactor and fouling the bag filter and ultrafilter. Since the receiving tank is aerated and the contents recirculated, some degradation occurs in this tank. A trash pump, P1, is used to transfer sludge to the SBR where it is diluted to the final working concentration of 20,000 ppm. Each run requires about 30 pounds of ammonium phosphate fertilizer, 7 pounds of yeast extract, and 4 pounds of casamino acids. A standard pH controller is used to maintain a pH of 7 to 7.5 by injecting 50% sodium hydroxide into the recirculation line.

Currently, a degradation cycle requires 5 days, at which time the aeration system and recirculation pump are turned off and the solids allowed to settle for 4-6 hours. As originally installed, the ultrafiltration unit required approximately 16 hours to process the contents of the reactor, **Figure 3**. Since these data were collected, the original tubular membranes have been replaced with higher capacity spiral wound membranes which halved the processing time. The system is set to leave 1,500 gallons of liquid (mostly biomass) in the bottom of the reactor that serves as seed for the next batch of oily sludge. Since the system is automated, the ultrafiltration unit runs overnight and the following morning the reactor is charged with the next batch of sludge.

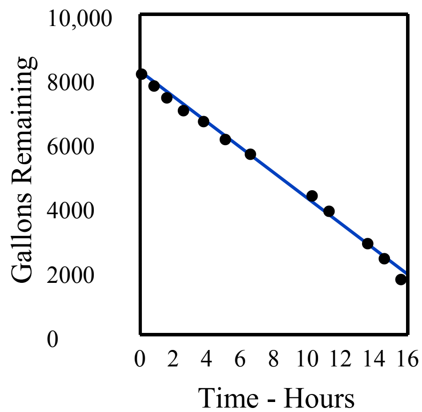

Figure 3. Permeate Output from the Ultrafiltration unit.

Either manual or automatic operation of the system is possible through the system controller to which all pumps, blowers, valves and sensors are interfaced. The controller is accessed through a touch screen which allows the operator to view tank levels, pH, and the status of all pumps and valves. In auto mode, the operator enters the number of days that the reactor will run, the amount of sludge to be transferred from the receiving tank, the dilution factor, and the settling time. When the tank has settled, the ultrafiltration system comes on line and processes the contents of the reactor. The system can also transfer sludge automatically from the receiving tank to the reactor and dilute it to a predetermined value entered by the operator. When sludge is delivered to the receiving tank, the operator enters the volume of sludge to be transferred and any dilution factor and the processor ensures that the entered values do not exceed the tank capacity.

4.3.4 Operational Testing. After verifying the integrity of the plumbing, valves and pumps, and proper operation of the blowers and control system, the reactor was charged with oily sludge from the BOWTS unit. This sludge was selected because it is dilute, ~1,500 ppm hydrocarbons, and in bench scale testing was shown to harbor a diverse population of hydrocarbon degrading bacteria. The goal during startup was to avoid overloading the system which could have inhibited bacterial growth. The first load of sludge was degraded within 10 days. To establish a robust bacterial population this process was repeated three times. Subsequently the reactor was charged with emulsified oil that had accumulated in the BOWTS load equalization tank, sludge produced by the BOWTS unit, and oily sludge collected by the shipyard during routine maintenance. To date more than 30,000 gallons of oily sludge have been successfully processed.

4.3.5 Test Results-Hydrocarbon Degradation. Initially the reactor was charged with oily sludge produced by the BOWTS unit. At regular intervals samples were taken and

analyzed for residual hydrocarbons, total bacteria, and hydrocarbon degrading bacteria, **Figures 4a and 4b** respectively.

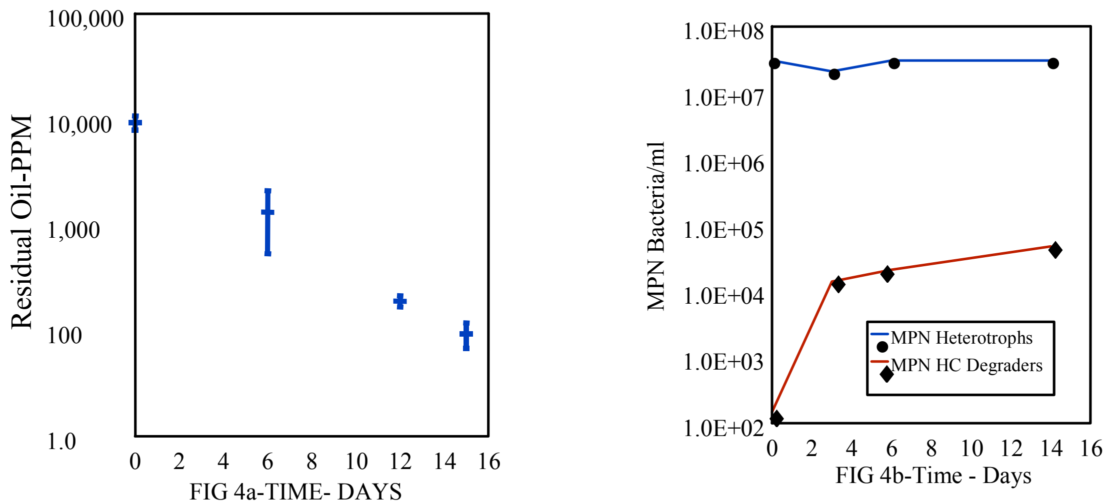

Figure 4. Hydrocarbon Degradation (a) and Bacterial Growth (b)
Data taken during startup of the 10,000 gallon sequencing batch reactor at PWC Pearl Harbor. Hydrocarbon concentrations are the average of three separate samples.

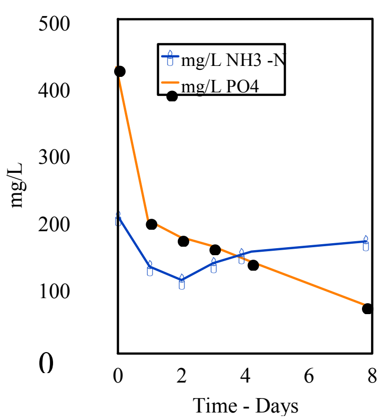

Figure 5. Consumption of Ammonia and Phosphorous During Hydrocarbon Degradation.

The data show a rapid outgrowth of the hydrocarbon degrading bacteria selected from a large population of heterotrophs that are found in the oily sludge. Outgrowth of the hydrocarbon degrading bacteria correlates with the degradation of the hydrocarbons in the oily sludge and the consumption of nitrogen and phosphorous, **Figure 5**. After 10 days, the air and recirculation were turned off and the reactor was allowed to settle and the supernatant run through the ultrafiltration unit. No hydrocarbons were detected in the permeate which was stored in tank T3 and used to dilute incoming sludge. Recycling of the bacteria has selected a robust bacterial population that now degrades sludge hydrocarbons in approximately 5 days. The concentration of hydrocarbons in the sludge that accumulated in the reactor after 1.5 years of operation was less than 500 ppm that was well within the allowable concentration for disposal at the landfarm. Since natural products artificially inflate the hydrocarbon concentration, the actual concentration of hydrocarbons derived from the oily sludge is considerably less than 500 ppm.

4.3.6 Test Results-Metals. Supernatant and solids that accumulate in the reactor were analyzed for priority metals, **Figure 6.** Copper, nickel, and zinc are the predominant metals, which is consistent with the origins of the sludge. Metals adsorption to bacterial cells and precipitation as oxyhydroxides accounts for the time dependent increase in metals concentration in the solids fraction, **Figure 6b.**

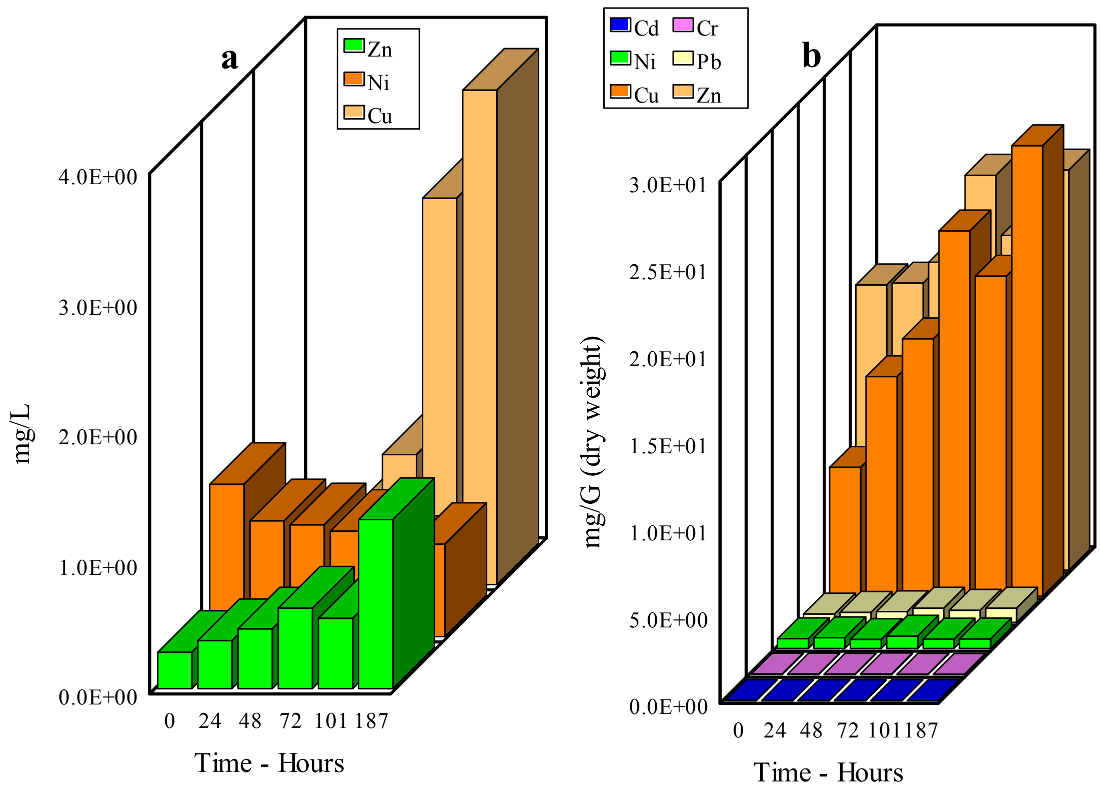

Figure 6. Metals in (a) Liquid Phase and (b) Solids.
Lead, chromium, and cadmium were not detected in the liquid phase.

4.3.7 Test Results- Reactor Bottoms Disposal. Although there is a six-fold decrease in solids when oily sludge is digested in the reactor, ~200 grams of biomass accumulate in the reactor during each run (**Figure 7**). The biological oxygen demand of accumulated biomass can adversely affect performance of the reactor and adversely affects performance of the bag filter and ultrafilter. The original workplan called for this material to be composted. However, this would have entailed additional expense related to segregation and monitoring of the compost piles to which this material was added. As an alternative, tank bottoms were simply hauled to the landfarm, **Figure 7.**

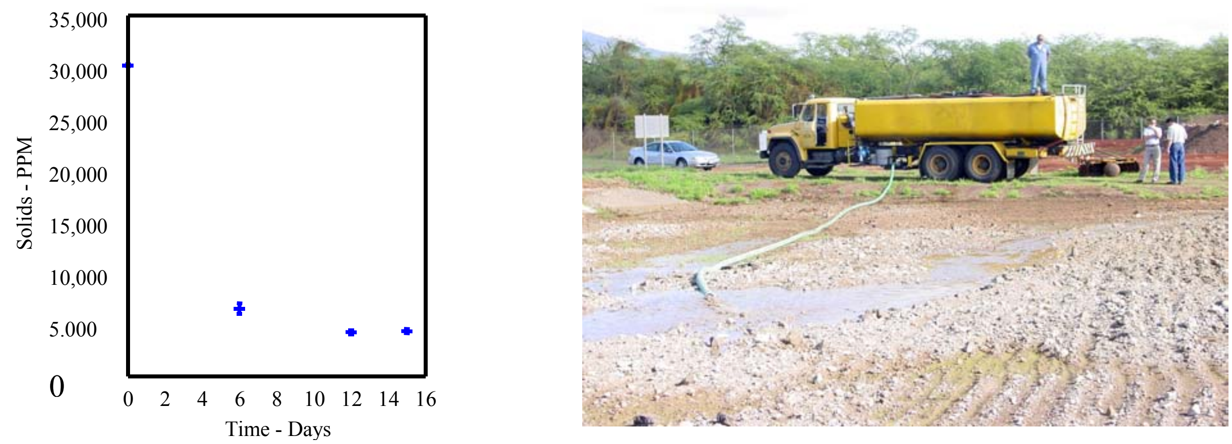

Figure 7. **Landfarming Accumulated Sludge.** *Tank bottoms were pumped into the vacuum truck and spread on the treatment cell at the landfarm. Inset shows solids production during reactor operation.*

4.3.8 Test Results-Emission of Priority Pollutants.

Oily sludge was suspended in water, stirred, aerated, and duplicate air samples were collected in Tedlar® bags and analyzed for priority pollutants. Since the objective was to estimate the maximum potential release of priority pollutants, degradation was minimized. Specifically, no nutrients were added, biologically active sludge was not included, and samples were collected after 2 hours. **Table 2**, shows the priority pollutants (BTEX) that were detected and their concentrations.

Table 2. Emission of Priority Pollutants from Oily Waste

Pollutant	Concentration ppm v/v Average ±SD
Benzene	0.044±0.021
Toluene	0.28±0.45
Ethylbenzene	0.85±0.3
Xylenes	2.77±0.95

Samples were also analyzed for priority pollutants containing reduced sulfur, **Table 3**. The results suggest that these compounds may be present, but at concentrations less than the minimum detection level. Since these compounds are rapidly oxidized, these results are what would be expected in a well-aerated system. In fact, when fresh oily sludge is added to either the 75 liter or 10,000 gallon reactor, there is a substantial and transient

(~2 hours) increase in oxygen consumption. While some fraction of this activity is due to biological activity, rapid oxidation of reduced sulfur compounds would also consume substantial amounts of oxygen.

Table 3. Emission of Sulfur Containing Priority Pollutants from Oily Waste

Pollutant	Result[a]	Minimum Detection Level ppm (v/v)
Hydrogen Sulfide	BDL	0.5
Carbonyl Sulfide	BDL	0.5
Methyl Mercaptan	BDL	0.5
Ethyl Mercaptan	BDL	0.5
Carbon disulfide	BDL	0.5
Dimethyl Sulfide	BDL	0.5
Total Sulfur	BDL	1.0

[a]BDL- Below Detection Level

Average concentrations in **Table 2**, were used to calculate the maximum potential emission of these compounds from the SBR. These calculations assume that no degradation occurs. However, the compounds in **Table 2** are some of the most readily degraded hydrocarbons and have not been observed in the 75 liter pilot scale reactor or the 10,000 gallon reactor. Furthermore, these concentrations may not be representative of all sources of oily sludge. Emission calculations used the full scale reactor design air flow of 100 cubic feet per minute (cfm) and assumed that the compounds were volatilized at constant concentration for eight hours. Given the volatility of the priority pollutants, this is not an unreasonable assumption. Emissions were calculated assuming that the reactor is charged with 1000 gallons (~8000 pounds) of fresh sludge twice a month, i.e., 24 runs per year. The results of these calculations are summarized in **Table 4.**

Table 4. Concentrations of Priority Pollutants Discharged to the Air During the Biological Treatment of Oily Waste

These calculations assume that no degradation occurs in the reactor.

Pollutant	Quantity Pounds/Run	Quantity Tons/Year
Benzene	1.17	0.014
Toluene	0.875	0.01
Ethylbenzene	30.8	0.37
Xylenes	100.4	1.2
Total	**133.2**	**1.6**

Even though the concentrations of sulfur containing priority pollutants (if present) were below the detection level, potential emissions (**Table 5**) of these compounds were calculated using the same assumptions. To make these calculations, concentrations of the

individual compounds were assumed to equal one-half the minimum detection level (**Table 3**). Even though these compounds are rapidly oxidized and readily degraded, it was assumed that no degradation occurred.

Table 5. Concentrations of Sulfur Containing Priority Pollutants Discharged to the Air During the Biological Treatment of Oily Waste

These calculations assume that no degradation occurs in the reactor.

Pollutant	Quantity Pounds/Run	Quantity Tons/Year
Hydrogen Sulfide	2.9	0.0345
Carbonyl Sulfide	5.1	0.0615
Methyl Mercaptan	4.1	0.0495
Ethyl Mercaptan	5.3	0.0635
Carbon disulfide	6.4	0.0775
Dimethyl Sulfide	5.3	0.0635
Total	**29.1**	**0.3500**

To minimize (eliminate) the emission of priority pollutants, exhaust air from the SBR is passed through compost biofilters (Biocubes, http://www.biocube.com/index.htm). The design capacity of each biofilter is 150 cfm. Since the design air flow of the SBR is 100 cfm, the combined capacity of the biofilters is ~80 % greater than the maximum air flow. To ensure adequate residence time, the biofilters are arranged so that the incoming air is split between the first two biofilters and the exhaust air from the first two biofilters is fed to the third biofilter. A separate fan is used to maintain a slight negative pressure in the exhaust air line that serves the reactor and receiving tank. Biofilters routinely remove more than 90% of BTEX from contaminated air. Thus, the yearly emissions of these compounds from the SBR might be expected to be less than 0.16 ton or 320 pounds per year. When biodegradation in the SBR (measured >99.5%) is included, total yearly emissions of BTEX are predicted to be less than 16 pounds per year. Actual measurements of priority air pollutants in the exhaust air prior to and after leaving the biocubes are in progress.

4.3.9 Test Results-Toxicity. Samples of raw and treated sludge have been assayed for toxicity using fathead minnows and Microtox®. While raw sludge was toxic in both assays, treated sludge was not toxic in either assay.

4.3.10 Test Results-Costs. Costs for biological treatment are summarized in **Table 6**. At Pearl Harbor the three tanks and ultrafiltration unit were obtained at no cost and the site was already prepared, which reduced the capital costs by $200K. Thus, capital costs at an installation without the infrastructure provided by PWC Pearl Harbor would cost an additional $200K. To calculate the economic viability, the costs in **Table 6** were entered into a spreadsheet that compares current practice (landfilling) with biological treatment and calculates the payback time. At PWC Pearl Harbor, the current practice is to drum and ship oily sludge off island at an annual cost of $190K. Disposal costs are reduced from $0.76/lb to $0.08/lb. Using these figures, the payback for the biological treatment is

less than two years, **Table 7**. An additional benefit is the elimination of liability that is difficult to quantify.

Table 6. Cost to Install and Operate a 10,000 Gallon Sequencing Batch Reactor to Treat Oily Sludge at PWC Pearl Harbor

Item	Cost
Capital Equipment	$200K
Labor	$47K
Utilities	$27.6K
Sewer and Landfarming	$3.6K
Miscellaneous	$2.5K
TOTAL	**280.7K**

Table 7. Economic Benefit of Biological Treatment Versus Landfilling Oily Sludge

Technology	Net Present Worth	Savings to Investment Ratio	Payback - Years
Biological Treatment	-$854,549.29	3.43	2

4.3.11 Test Results-Permits. Since this was a pilot project, an operating permit was not required. However, the unit is sited at the BOWTS facility that is already permitted to handle and dispose of oily sludge. Thus, it will only require a modification of the existing permit. Disposal of biomass that accumulates in the reactor by landfarming has been permitted by the Hawaii Department of Health. The major issue is the potential for air emissions. Total air emissions are governed by a basewide permit which limits the total quantity of priority air pollutants that can be emitted. If emissions from the reactor facility cause the permitted levels to be exceeded, then they have to be reduced. However, the goal is not to emit any priority air pollutants. Data collected to date suggest little or no emission of priority air pollutants and preliminary testing of emissions entering into and exiting the biofilters support this conclusion.

5.0 CONCLUSIONS. This project demonstrated that a sequencing batch reactor for the on-site biological treatment of oily sludge is easily assembled on site using off-the-shelf components and surplus tanks. This approach eliminates the sludge at significant cost savings that for most installations would be recovered in 2 years. An additional advantage is that the long-term liability associated with landfilling oily sludge is eliminated. Furthermore, the reactor facility is easy to operate and maintain and is enthusiastically operated by PWC personnel.

6.0 POINTS OF CONTACT

Program Manager
Mr. George Wu, Code ESC45
Naval Facilities Engineering Service Center
Port Hueneme, CA 93043-4370
(805) 982-4853

Branch Head
Mr. Jeff Heath
Naval Facilities Engineering Service Center
Pollution Prevention Technology Development Branch
Port Hueneme, CA 93043-4370
(805) 982-1600

Lead Project Engineer
Mr. Sonny F. Maga, P.E., Code ESC 421
Naval Facilities Engineering Service Center
Pollution Prevention Technology Development Branch
Port Hueneme, CA 93043-4370
(805) 982-1340

Technical Consultant
Fred Goetz, Ph.D.,
University of California Santa Barbara
Port Hueneme, CA 93043-4370
(805) 982-1184

Customer/Partner
Steve Christiansen, Environmental Department, Treatment, Analysis and Disposal Director
PWC Pearl, Code 340,
Building 220,
Pearl Harbor, HI 96860-5470
(808) 474-1556

Contractor
Randall Jones,
Wastewater Resources Inc.
9445 East Doubletree Ranch Road
Scottsdale, AZ 85258
(800) 266-9897